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Photonic Crysral Based Biosensor for Brain Tumour Detection

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INTRODUCTION

Early cancer identification has been more important in recent years due to the potential to enhance patient outcomes through earlier management. Traditional diagnostic approaches, while successful, sometimes have drawbacks such as limited sensitivity, high prices, and the requirement for sophisticated procedures. To overcome these problems, novel biosensing technologies have evolved that improve performance and accessibility. Photonic crystal- based biosensors stand out for their excellent sensitivity and specificity in detecting biomolecular interactions.

In the same way that a semiconductor affects electron flow, photonic crystals are optical materials with periodic features that affect photon flow. These materials can provide extremely sensitive optical sensors that are capable of identifying even the tiniest changes in the surrounding environment when combined with biosensor platforms.

Because photonic crystal technology can provide high-resolution, real-time, label-free detection, it holds enormous potential for the identification of cancer cells. Through the use of photonic crystals' special optical characteristics, scientists can create sensors that can recognize cancerous cells by their unique chemical signatures. This method not only improves cancer detection accuracy but also expedites the procedure, which could lead to more accessibility to diagnostic tools.

The utilization of photonic crystal technology in cancer cell detection is the main emphasis of this work. We go over the fundamentals of photonic crystal technology, point out new developments in sensor architecture, and talk about the difficulties in converting these developments into useful diagnostic instruments. Our goal is to demonstrate how photonic crystal-based biosensors could transform cancer diagnosis and enable individualized care through this analysis.

LITERATURE SURVEY

C. Malek et al. proposed an extremely sensitive tunable biosensor for cancer brain tumor detection utilizing a defective 1D photonic crystal comprising alternating layers of silicon and air and $YBa_2Cu_3O_7/SiO_2$-coated defect cavity. The device augments the matter-light interaction as well as tuneability by change in temperature as well as in angle. Simulated by the transfer matrix method, the sensor can detect changes in CSF refractive index with ultra-high sensitivity (4139.24 nm/RIU), a quality factor of 10^3, and a detection limit of 10^{-5}. A refractive index greater than 1.395 signifies malignancy because of variations in protein levels.[1]

Venkateswara Rao Kolli et al. demonstrated a high Q-factor and highly sensitive photonic crystal micro-ring resonator-based pressure sensor. The sensor is made up of ten hexagonal micro-ring resonators formed by line faults and accurately placed between two straight waveguides. Coupled with a diaphragm structure, the sensor demonstrates a good Q-factor of 26,180 and sensitivity of 1.37 nm/MPa. The response output demonstrates a linear shift of wavelength in the pressure range of 0 to 6 MPa, indicating the capability of the device for accurate pressure measurement.[2]

Mojtaba Hosseinzadeh Sani et al. proposed a hexagonal photonic crystal structure based high- resolution biosensor that detects two different chemicals simultaneously, for instance, tear fluid and human blood.It consists of two nonlinear nanocavities that are able to detect changes in resonance wavelength and thus enable discrimination between pathological and healthy conditions such as diabetes and cancer. It has high figure of merit (FOM) of up to 1550.11 RIU^{-1} and large range sensitivity of 1294 to 3080 nm/RIU. Its transmission efficiency of between 91% and 100% enables high accuracy and efficiency. Its compactness and capability to analyze two samples at once make it the ideal device for fast non-invasive medical diagnosis.[3]

Zongren Dai, and others designed an SPR biosensor that is integrated with laser heterodyne feedback interferometry for the fast and high- sensitivity detection of COVID-19. In the record- breaking sensor, label-free, real-time detection of the SARS-CoV-2 spike protein relied on the changes in refractive index being transduced by changes in light intensity. Antigen detection in less than one minute with linear range of 0.01 ng/mL to 1000 ng/mL with high resolution of 3.75×10^{-8} RIU, and a detection limit of 0.08 pg/mL. With the assistance of anti-SARS-CoV-2 monoclonal antibodies to bind antigens specifically, the technique is rapid and accurate alternative to traditional RT-PCR testing.[4]

Fatemeh Baraty et al. developed a label-free biosensor for the identification of cancer cells using a two-dimensional photonic crystal ring resonator. The sensor has a silicon rod array in cubic lattice to detect the changes in refractive index using a change in the resonant wavelength. The biosensor is able to differentiate between cancer and normal cells like breast, cervical, and blood cancers using defect engineering and cubic lattice to detect the changes in refractive index using a change in the resonant wavelength.

The biosensor is able to differentiate between cancer and normal cells like breast, cervical, and blood cancers using defect engineering and finite- difference time-domain simulations. The sensor has high sensitivity of 324.28 nm/RIU, quality factor of 3690, and wide changes in wavelength. The biosensor has a compact, efficient, and low- cost method for real-time detection of cancer.[5]

Nazmi A. Mohammed et al. developed an improved two-dimensional photonic crystal biosensor nanocavity structure for accurate brain tumor detection. The compact sensor, 7.8 x 5.5 μm^2 in dimensions, can distinguish normal brain tissues from tumors like glioblastoma, medulloblastoma, and lymphoma. The biosensor is more efficient, with sensitivity of 1332 nm/RIU, high quality factor of 16,254, and low detection limit of 9.08×10^{-6} RIU. The device consists of a hexagonal array of silicon rods with a central nanocavity, improving light-tissue interaction and accurate tissue classification. Its architecture is compatible with existing fabrication methods, and it operates at resonant wavelengths overlapping with commercial optical fiber windows, making it appropriate for practical diagnostic applications.[6]

Yang Yang et al. explored a high-sensitivity photonic crystal biosensor for cancer diagnostics. The biosensor consists of a hexagonal resonant cavity silicon-based photonic crystal structure enclosed within a triangular lattice, optimized in the wavelength ranges of 1188-1968 nm. It is highly sensitive up to 915.75 nm/RIU with a quality factor of 980 and an unprecedented detection limit of 0.000236 RIU. It discriminates accurately between cancer cells and normal cells by detecting a change in refractive index. Its performance is significantly enhanced with innovative dielectric pillar topologies compared to a conventional biosensor. The new design possesses a huge potential towards early cancer diagnostics and other applications in the pharmaceutical field.[7]

Shiva Khani and Mohsen Hayati introduce two new optical biosensor structures for basal cell carcinoma detection using metal-insulator-metal (MIM) plasmonic devices and one-dimensional photonic crystals (PC) technologies. Owing to their high sensitivity, these devices employ photonic band gaps (PBGs) with sharp edges within the transmission spectrum. The first sensor with figure of merit (FOM) of 156.2 RIU^{-1} and sensitivity of 718.6 nm/RIU is constructed by building PBGs from GaAs layers. The second structure increases transmittance with tapered resonators with sensitivity of 714.3 nm/RIU and FOM of 60.1 RIU^{-1}. These optimized biosensors with the application of finite-difference time-domain (FDTD) methods are introduced as promising devices for bio-optical applications, especially for the detection.[8]

Hassan Sayed et al. suggested a new salinity sensor based on Tamm- Plasmon-polariton (TPP) resonance in one-dimensional photonic crystals (PCs) of three different surface morphologies: normal, textured, and sawtooth. Later, Using COMSOL simulations, the study concluded that the alteration of the surface shape, particularly to a sawtooth profile, greatly increases sensor sensitivity.

Sawtooth shape indicated the best performance with the optimal sensitivity value of 612.29 nm/RIU and figure of merit (FOM) of 199 RIU^{-1}. This cost-effective and highly efficient sensor concept has enormous potential for desalination and other salinity sensing applications.[9]

Jingjing Sun et al. fabricated an Optical Coherence Tomography (OCT) device based on MEMS to study refractive index (RI) alterations in acute rat brain tissue slices subjected to 20% to 80% compressions. The study entailed numerous investigations of different brain areas, including the corpus callosum and cerebral cortex, and reached the conclusion that the RI is site- dependent and the corpus callosum possesses a higher RI compared to the adjacent tissues. Also, homogeneous RI increments were found under mechanical stress, which were related to fluid displacement and tissue compression. These findings suggest the significance of RI information to improve optical imaging quality, facilitate clinical diagnoses, and enhance OCT elastography and mechanical testing methods.[10] Yin Zhang et al. used a novel metamaterial absorber at microwave frequencies for non- destructive grain quality monitoring. The sensor consists of a metallic ground plane, a sensor layer filled with grain, and an array of cross-resonator on an

ultrathin substrate, which possesses the capability to create high sensitivity to variations in grain properties. Experimental results demonstrate that the absorber can identify changes in the resonant frequency due to variation in grain dielectric properties and thus adulteration detection—e.g., fresh and spoiled rice. It can also identify different grains, e.g., rice, peanuts, corn, and wheat, due to their respective resonance frequencies. The absorber is fast, precise, and non- destructive and is a good candidate for agricultural quality inspection and monitoring.[11]

Auguié et al. present a novel optical sensing technology based on Tamm plasmon resonance (TPR) with the help of characteristic optical properties of mesoporous SiO_2 and TiO_2 multilayers. Such multilayers are a distributed Bragg reflector (DBR) and are joined with a gold film to create a structure to support Tamm plasmon modes. Auguié et al. state that the abrupt Tamm resonance mode, which exists in the stop- band of DBR, is highly sensitive to variation in the refractive index of the surrounding. Porosity of SiO_2 and TiO_2 layers allows the target analytes to access positions of high electric field strength to increase detection efficiency. Auguié et al. highlight that this TPR-based sensor, because of its suitability, can be used in applications in spectroscopy and chemical functionalization.[12]

Arafa H. Aly et al. present a new optical biosensor for tuberculosis detection based on one- dimensional photonic crystals (1D-PCs). The light incidence angle and thickness of the defect layer are optimized to make the sensor's resonance cavity highly sensitive. Experimental results demonstrate the sensor's capability to detect tuberculosis-induced differences in blood levels, with a highest sensitivity of 1390 nm/RIU. The biosensor is low cost, simple, and industrially portable and has vast potential to transform tuberculosis diagnosis, particularly in poor- resource settings.[13]

Arafa H. Aly et al. report the fabrication of a one- dimensional photonic crystal biosensor that can detect two key reproductive hormones— progesterone and estradiol—in blood samples. The biosensor consists of an air-filled hollow structure contained within MgF_2 layers with alternately embedded SiO_2 and Si. Sensitivity is achieved by monitoring changes in defect modes in photonic band gaps, which correspond to changes in the hormone concentrations. The device is extremely sensitive—up to 98.92 nm/nmol/L for progesterone and 96.13 nm/nmol/L for estradiol—with high quality factors and figures of merit. The findings suggest that the biosensor can be employed as an effective and low-cost tool for gynecological diagnosis in biomedical applications.[14]

Ashraf A.M. Khalaf et al. present the design of a high-sensitivity, compact biosensor for blood component sensing using a nanocavity-coupled photonic crystal platform. The sensor is a hexagonal lattice of silicon rods with a double circular-hole defect, with ultra-high quality factors, a very small footprint, and high sensitivity. From finite-difference time-domain (FDTD) and plane-wave expansion (PWE) simulations, the device is demonstrated to sense eleven major blood components. The work establishes new standards for refractive-index- based biological sensing with potential for future advanced, miniaturized diagnostic technologies.[15]

The studies mentioned above demonstrate the progress of photonic and plasmonic biosensors in terms of structure, material selection, and detecting capabilities. Previous research has established a solid foundation by investigating numerous configurations such as micro-ring resonators, nanocavities, and defect-based photonic crystals for sensitive and selective biosensing. These studies not only prove the efficacy of refractive index-based detection, but also demonstrate the possibility of changing sensor performance by varying geometric and optical factors. Building on these findings, our proposed methodology seeks to create an optimal biosensor structure with better sensitivity and biomedical applicability.

METHODOLOGY

Figure 1 shows a schematic illustration of a photonic crystal (PhC). It consists of a hexagonal lattice sandwiched between two waveguides with line faults. The PhC has four ports: an input, a through, a forward drop, and a backward drop port.

The design parameters are shown in Table 1. A hexagonal lattice is preferred over a square lattice because it has a substantially larger photonic bandgap. The array's hole radius is 136 nm, whereas its lattice constant is 420 nm. After studying the bandgap size changes dependent on slab thickness, the PhC slab thickness was determined to be 220 nm. This paper describes the creation of a PhC biosensor designed to detect the presence of cervical cancer (Hela cells).

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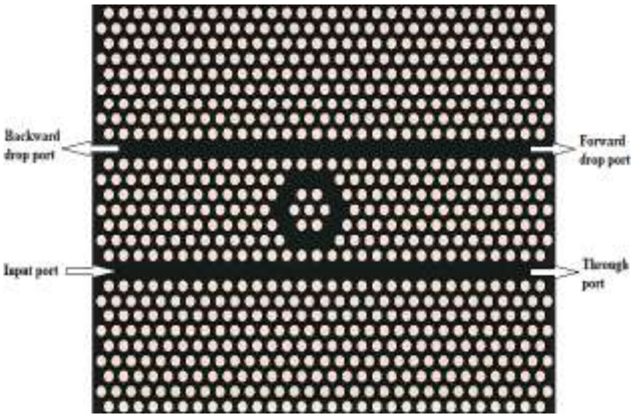

Figure.1 The Diagram showing the design of Phc

Brain tumors are often caused by a combination of genetic changes and environmental factors. Malignant glioblastoma cell lines have a refractive index (RI) of 1.396, while healthy brain cells have a RI of 1.372. Brain tumors can develop in any section of the brain, including the frontal and temporal lobes, and can afflict individuals of all genders. Brain tumors make up 20% of all cancers and kill millions of people.

It was found that when exposed to particular oncogenic stimuli, the brain tumor cells displayed aberrant growth patterns. In contrast to normal brain cells, which had a refractive index (RI) of 1.425, these tumor cells had a RI of 1.453. Brain tumors are among the most common forms of malignant brain disorders, including gliomas and meningiomas. Neurological cancers account for 20% of all cancers that impact millions of individuals globally.

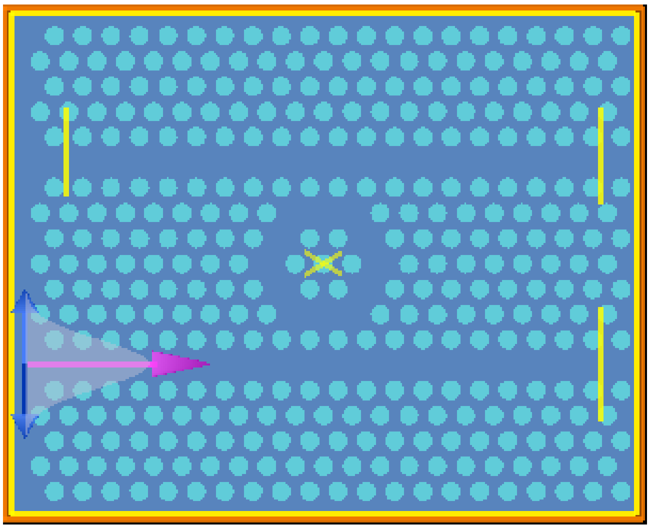

Figure 2. Designed Structure of Rhombic PhC

Table 1. PhC design parameters

Parameters	Values
Structure	Holes in the Dielectric Slab
Configuration	Hexagonal
Shape of Holes	Circular
Lattice Constant	420nm
The holes' radius	136nm
RI of Holes	RI of healthy and malignant cells that’s fills in the holes
Hexagonal lattice dimension	21 X 19
The slab's thickness and the holes in it	220nm

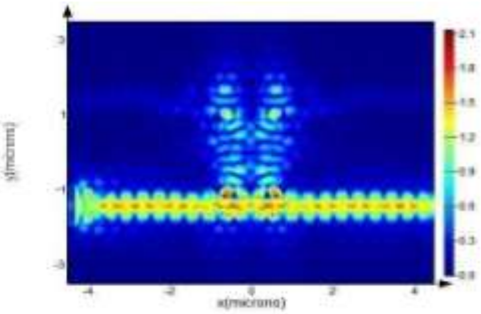

Figure 3. (E) Field magnitude at on-resonance

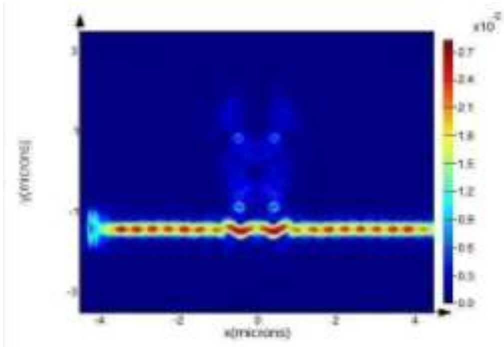

Figure 4. (E) Field magnitude at off-resonance

Figures 3 and 4 show the magnitudes of (E) fields at off-resonant and on-resonant states, respectively Because cancerous cells have more protein than
healthy ones, their RI is higher. The ability of the biosensor to react to variations in RI makes it

CSF	**1.3333**	**1620.14**	**1975.78**	119.5431
White matter	**1.4121**	**1629.56**	**1335.70**	115.7488

Brain Tissues RI λd (μm) Q Factor S(μm/RIU)

simple to distinguish between healthy and	**Low grade**	**1.4320**	**1631.88**	**1337.606**
cancerous cells. Cell liquid contents are believed	**glioma Wall of solid**	**1.3412**	**1621.37**	**1318.18**

to be between 30 and 70 percent for normal cells and 80 percent for malignant cells. This paper explains how to use the RI change to diagnose malignancy.

RESULTS AND DISCUSSION

The FDTD approach is used to create mathematical models for the biosensor. The PhC's operating frequency is exactly the same as the light source input frequency. The light eventually passes through the waveguide before exiting at the output port. The purpose of this research is to use a biosensor to detect cancer cells. The approach detects changes in the refractive index, which manifest as variations in the resonance wavelength of the output transmission. This trait distinguishes between malignant and healthy cell lines. Modifying the refractive index of the holes evaluates the biosensor's sensitivity to cancerous cells.

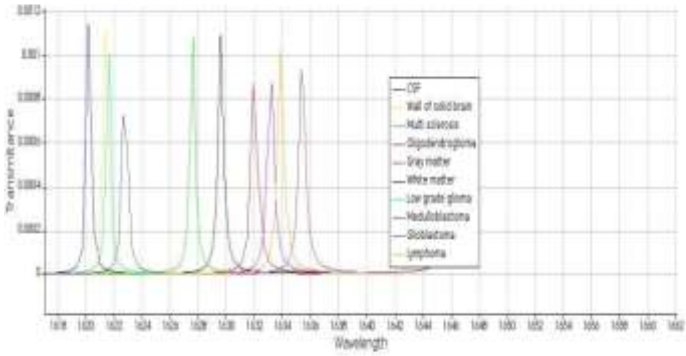

Figure 5. Shift in Resonance wavelength for Brain tumor cells

Table 2. The refractive index(RI), central wavelength of defect mode (λ_d),Q factor and Sensitivity(S) of the proposed design.

brain				
Medulloblas toma	**1.4412**	**1633.23**	**1067.47**	
Multi- sclerosis	**1.3425**	**1621.65**	**1329.22**	117.3252
Lymphoma	**1.4591**	**1635.29**	**1143.55**	
Gray matter	**1.3951**	**1627.62**	**1808.46**	119.8437

The Q and sensitivity effect illustrates a biosensor's performance. The Q is defined as the ratio of the wavelength shift at full width half maximum (FWHM) the resonant wavelength.

$$Q = \frac{\lambda 0}{FWHM} \quad (1)$$

The wavelength shift, represented by 'λ0', is represented by 'FWHM'.
The ratio of intensity to change in refractive index is known as sensitivity.

$$\text{Sensitivity} = \frac{\text{Change in wavelength}}{\text{Change in refractive index}} \quad (2)$$

CONCLUSION

We examined a photonic crystal-based biosensor for identifying brain tumor cells using FDTD simulations. By enhancing sensitivity and detection accuracy, the simulations offered profound insights into light-matter interactions. Our findings show that photonic crystal biosensors have the potential to be a trustworthy and non-invasive diagnostic method.

REFERENCES

[1]. Abohassan, K.M., Ashour, H.S., & Abadla, M.M. (2021). A 1D photonic crystal-based sensor for detection of cancerous blood cells. Optical and Quantum Electronics, 53(7), 356.

[2]. Huang, C.-S., George, S., Lu, M., Chaudhery, V., Tan, R., Zangar, R.C., & Cunningham, B.T. (2011). Application of photonic crystal enhanced fluorescence to cancer biomarker microarrays. Analytical Chemistry,

83(4), 1425-1430.

[3]. Panda, A., Pukhrambam, P.D., Wu, F., & Belhadj, W. (2021). Graphene-based 1D defective photonic crystal biosensor for real-time detection of cancer cells. The European Physical Journal Plus, 136(8), 809.

[4]. Chopra, H., Kaler, R.S., & Painam, B. (2016). Photonic crystal waveguide-based biosensor for detection of diseases. Journal of Nanophotonics, 10(3), 036011.

[5]. Roy, S.K., & Sharan, P. (2018). Photonic crystal based sensor for DNA analysis of cancer detection. In A. Mishra, A. Basu, & V. Tyagi (Eds.), Silicon Photonics & High Performance Computing (pp. 79-85). Springer.

[6]. Sharma, S., & Tharani, L. (2024). Photonic crystal fiber sensor design for enhanced tumor detection: Structural optimization and sensitivity analysis. Photonics Letters of Poland, 16(2), 25- 27.

[7]. Baratye, F., & Hamedi, S. (2023). Label-free cancer cell biosensor based on photonic crystal ring resonator. Results in Physics, 46, 106317.

[8]. Shiramin, L.A., Kheradmand, R., & Abbasi, A. (2013). High-sensitive dual-hole defect refractive index sensor based on 2-D photonic crystal.

[9]. Mazzone, P., Jain, P., Arroliga, A.C., & Matthay, R.A. (2002). Bronchoscopy and needle biopsy techniques for diagnosis and staging of lung cancer. Clinics in Chest Medicine, 23(1), 137- 158.

[10]. Asuvaran, A., & Elathrasan, G. (2022). Design of two-dimensional photonic crystal-based biosensor for abnormal tissue analysis. Silicon, 14(12), 7203- 7210.

[11]. Kumar, R., Bharti, G.K., & Bindal, R.K. (2022). Modeling and simulation of an optical sensor for cancer cell detection. International Journal of Electrical and Electronics Research, 10(4), 792- 795.

[12]. Lin, B., Li, P., & Cunningham, B.T. (2006). A label-free biosensor-based cell attachment assay for characterization of cell surface molecules. Sensors and Actuators B: Chemical, 114(2), 559-564.

[13]. Chan, L.L., Gosangari, S.L., Watkin, K.L., & Cunningham, B.T. (2007). A label-free photonic crystal biosensor imaging method for detection of cancer cell cytotoxicity and proliferation. Apoptosis, 12(6), 1061-1068.

[14]. George, S., Bhalerao, S.V., Lidstone, E.A., Ahmad, I.S., Abbasi, A., Cunningham, B.T., & Watkin, K.L. (2010). Cytotoxicity screening of Bangladeshi medicinal plant extracts on pancreatic cancer cells. BMC Complementary and Alternative Medicine, 10, 52.

[15]. Shamah, S.M., & Cunningham, B.T. (2011). Label-free cell-based assays using photonic crystal optical biosensors. The Analyst, 136(6), 1090-1102.

[16]. Shiramin, L.A., Kheradmand, R., & Abbasi, A. (2013). High-sensitive dual-hole defect refractive index sensor based on 2-D photonic crystal. IEEE Sensors Journal, 13(5), 1483- 1486.

[17]. Mazzone, P., Jain, P., Arroliga, A.C., & Matthay, R.A. (2002). Bronchoscopy and needle biopsy techniques for diagnosis and staging of lung cancer. Clinics in Chest Medicine, 23(1), 137- 158.

[18]. Verma, S., Choyke, P.L., Eberhardt, S.C., Oto, A., Tempany, C.M., Turkbey, B., & Rosenkrantz, A.B. (2017). The current state of MR imaging–targeted biopsy techniques for detection of prostate cancer. Radiology, 285(2), 343-356.

[19]. Pérez, M.G., Sarrión, J.V., Bagán, Y.J., Margaix, M., & Marzal, C. (2015). Utility of imaging techniques in the diagnosis of oral cancer. Journal of Cranio- Maxillofacial Surgery, 43(9), 1880- 1894.

[20]. Jaglan, P., Dass, R., & Duhan, M. (2019). Breast cancer detection techniques: Issues and challenges.